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# PATENT APPLICATION

## IN-SITU DETECTION OF THIN-METAL INTERFACE USING HIGH RESOLUTION SPECTRAL ANALYSIS OF OPTICAL INTERFERENCE


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# IN-SITU DETECTION OF THIN-METAL INTERFACE USING HIGH RESOLUTION SPECTRAL ANALYSIS OF OPTICAL INTERFERENCE

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## CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. Patent Application No. 09/812,535, filed March 19, 2001, entitled "In-Situ Detection of Thin-Metal Interface Using Optical Interference," and is related to U.S. Patent Application No. __________ (Attorney Docket No. LAM2P253.CIP1), filed October 12, 2001, entitled "In-Situ Detection of Thin-Metal Interface Using Optical Interference via a Dynamically updated Reference," both of which are incorporated herein by reference.

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

This invention relates generally to endpoint detection in a chemical mechanical polishing process, and more particularly to endpoint detection using optical interference of a broad reflectance spectrum.

### 2. Description of the Related Art

In the fabrication of semiconductor devices, typically, the integrated circuit devices are in the form of multi-level structures. At the substrate level, transistor devices having diffusion regions are formed. In subsequent levels, interconnect metallization lines are patterned and electrically connected to the transistor devices to define the desired functional device. As is well known, patterned conductive layers are insulated

from other conductive layers by dielectric materials, such as silicon dioxide. As more metallization levels and associated dielectric layers are formed, the need to planarize the dielectric material increases. Without planarization, fabrication of additional metallization layers becomes substantially more difficult due to the higher variations in the surface topography. In other applications, metallization line patterns are formed in the dielectric material, and then metal chemical mechanical polishing (CMP) operations are performed to remove excess metallization.

In the prior art, CMP systems typically implement belt, orbital, or brush stations in which belts, pads, or brushes are used to scrub, buff, and polish one or both sides of a wafer. Slurry is used to facilitate and enhance the CMP operation. Slurry is most usually introduced onto a moving preparation surface, *e.g.*, belt, pad, brush, and the like, and distributed over the preparation surface as well as the surface of the semiconductor wafer being buffed, polished, or otherwise prepared by the CMP process. The distribution is generally accomplished by a combination of the movement of the preparation surface, the movement of the semiconductor wafer and the friction created between the semiconductor wafer and the preparation surface.

Figure 1A shows a cross sectional view of a dielectric layer 102 undergoing a fabrication process that is common in constructing damascene and dual damascene interconnect metallization lines. The dielectric layer 102 has a diffusion barrier layer 104 deposited over the etch-patterned surface of the dielectric layer 102. The diffusion barrier layer, as is well known, is typically titanium nitride (TiN), tantalum (Ta), tantalum nitride (TaN) or a combination of tantalum nitride (TaN) and tantalum (Ta). Once the diffusion barrier layer 104 has been deposited to the desired thickness, a copper layer 106 is formed

over the diffusion barrier layer in a way that fills the etched features in the dielectric layer 102. Some excessive diffusion barrier and metallization material is also inevitably deposited over the field areas. In order to remove these overburden materials and to define the desired interconnect metallization lines and associated vias (not shown), a chemical mechanical planarization (CMP) operation is performed.

As mentioned above, the CMP operation is designed to remove the top metallization material from over the dielectric layer 102. For instance, as shown in Figure 1B, the overburden portion of the copper layer 106 and the diffusion barrier layer 104 have been removed. As is common in CMP operations, the CMP operation must continue until all of the overburden metallization and diffusion barrier material 104 is removed from over the dielectric layer 102. However, in order to ensure that all the diffusion barrier layer 104 is removed from over the dielectric layer 102, there needs to be a way of monitoring the process state and the state of the wafer surface during its CMP processing. This is commonly referred to as endpoint detection. Endpoint detection for copper is performed because copper cannot be successfully polished using a timed method. A timed polish does not work with copper because the removal rate from a CMP process is not stable enough for a timed polish of a copper layer. The removal rate for copper from a CMP process varies greatly. Hence, monitoring is needed to determine when the endpoint has been reached. In multi-step CMP operations there is a need to ascertain multiple endpoints: (1) to ensure that Cu is removed from over the diffusion barrier layer; (2) to ensure that the diffusion barrier layer is removed from over the dielectric layer. Thus, endpoint detection techniques are used to ensure that all of the desired overburden material is removed.

Many approaches have been proposed for the endpoint detection in CMP of metal. The prior art methods generally can be classified as direct and indirect detection of the physical state of polish. Direct methods use an explicit external signal source or chemical agent to probe the wafer state during the polish. The indirect methods on the other hand monitor the signal internally generated within the tool due to physical or chemical changes that occur naturally during the polishing process.

Indirect endpoint detection methods include monitoring: the temperature of the polishing pad/wafer surface, vibration of polishing tool, frictional forces between the pad and the polishing head, electrochemical potential of the slurry, and acoustic emission. Temperature methods exploit the exothermic process reaction as the polishing slurry reacts selectively with the metal film being polished. U.S. Patent No. 5,643,050 is an example of this approach. U.S. Patent No. 5,643,050 and U.S. Patent No. 5,308,438 disclose friction-based methods in which motor current changes are monitored as different metal layers are polished.

Another endpoint detection method disclosed in European application EP 0 739 687 A2 demodulates the acoustic emission resulting from the grinding process to yield information on the polishing process. Acoustic emission monitoring is generally used to detect the metal endpoint. The method monitors the grinding action that takes place during polishing. A microphone is positioned at a predetermined distance from the wafer to sense acoustical waves generated when the depth of material removal reaches a certain determinable distance from the interface to thereby generate output detection signals. All these methods provide a global measure of the polish state and have a strong dependence on process parameter settings and the selection of consumables. However, none of the

methods except for the friction sensing have achieved some commercial success in the industry.

Direct endpoint detection methods monitor the wafer surface using acoustic wave velocity, optical reflectance and interference, impedance/conductance, electrochemical potential change due to the introduction of specific chemical agents. U.S. Patent No. 5,399,234 and U.S. Patent No. 5,271,274 disclose methods of endpoint detection for metal using acoustic waves. These patents describe an approach to monitor the acoustic wave velocity propagated through the wafer/slurry to detect the metal endpoint. When there is a transition from one metal layer into another, the acoustic wave velocity changes and this has been used for the detection of endpoint. Further, U.S. Patent No. 6,186,865 discloses a method of endpoint detection using a sensor to monitor fluid pressure from a fluid bearing located under the polishing pad. The sensor is used to detect a change in the fluid pressure during polishing, which corresponds to a change in the shear force when polishing transitions from one material layer to the next. Unfortunately, this method is not robust to process changes. Further, the endpoint detected is global, and thus the method cannot detect a local endpoint at a specific point on the wafer surface. Moreover, the method of the 6,186,865 patent is restricted to a linear polisher, which requires an air bearing.

There have been many proposals to detect the endpoint using the optical reflectance from the wafer surface. They can be grouped into two categories: monitoring the reflected optical signal at a single wavelength using a laser source or using a broad band light source covering the full visible range of the electromagnetic spectrum. U.S. Patent No. 5,433,651 discloses an endpoint detection method using a single wavelength

in which an optical signal from a laser source is impinged on the wafer surface and the reflected signal is monitored for endpoint detection. The change in the reflectivity as the polish transfers from one metal to another is used to detect the transition.

Broad band methods rely on using information in multiple wavelengths of the electromagnetic spectrum. U.S. Patent No. 6,106,662 discloses using a spectrometer to acquire an intensity spectrum of reflected light in the visible range of the optical spectrum. Two bands of wavelengths are selected in the spectra that provide good sensitivity to reflectivity change as polish transfers from one metal to another. A detection signal is then defined by computing the ratio of the average intensity in the two bands selected. Significant shifts in the detection signal indicate the transition from one metal to another.

A common problem with current endpoint detection techniques is that some degree of over-etching is required to ensure that all of the conductive material (*e.g.*, metallization material or diffusion barrier layer 104) is removed from over the dielectric layer 102 to prevent inadvertent electrical interconnection between metallization lines. A side effect of improper endpoint detection or over-polishing is that dishing 108 occurs over the metallization layer that is desired to remain within the dielectric layer 102. The dishing effect essentially removes more metallization material than desired and leaves a dish-like feature over the metallization lines. Dishing is known to impact the performance of the interconnect metallization lines in a negative way, and too much dishing can cause a desired integrated circuit to fail for its intended purpose.

In view of the foregoing, there is a need for endpoint detection systems and methods that improve accuracy in endpoint detection. In addition, the systems and methods should be able to accurately determine film and layer thickness.

## SUMMARY OF THE INVENTION

Broadly speaking, the present invention fills these needs by an providing high resolution optical endpoint detection system that utilizes optical interference to determine when an endpoint has been reached, such as when metal layer has reached a thin metal zone during a CMP process. In one embodiment, a method for detecting an endpoint during a CMP process is disclosed. A reflected spectrum data sample is received that comprises a plurality of values corresponding to a plurality of spectrums of light reflected from an illuminated portion of the surface of a wafer. Outside spectrum data is extrapolated using a linear combination of the values of the reflected spectrum data sample, and an endpoint is determined based on optical interference occurring in the reflected spectrum data.

In a further embodiment, an endpoint detection apparatus for detecting an endpoint during a CMP process is disclosed. The endpoint detection apparatus includes a broad band light source for illuminating a portion of a surface of a wafer, and an optical detector for receiving reflected spectrum data sample. The reflected spectrum data sample comprises a plurality of values corresponding to a plurality of spectrums of light reflected from the illuminated portion of the surface of the wafer. The endpoint detection apparatus further includes logic that extrapolates outside spectrum data using a linear combination of the values of the reflected spectrum data sample, and logic that determines an endpoint based on optical interference occurring in the reflected spectrum data.

Another method for detecting an endpoint during a chemical mechanical polishing (CMP) process is disclosed in a further embodiment of the present invention. As above, a

reflected spectrum data sample is received that comprises a plurality of values corresponding to a plurality of spectrums of light reflected from an illuminated portion of the surface of a wafer. The reflected spectrum data sample is decomposed into noise sub-space values and signal sub-space values, and the noise sub-space values are truncated. In addition, outside spectrum data is extrapolated using a linear combination of the values of the reflected spectrum data sample. In this manner, an endpoint can be determined based on optical interference occurring in the reflected spectrum data.

As will be seen, the embodiments of the present invention use optical interference instead of mere changes in the surface reflectivity as in conventional endpoint detection. Thus, the embodiments of the present invention advantageously provide increased sensitivity and robustness in endpoint detection. In addition to endpoint detection, the embodiments of the present invention advantageously can be used to determine the thickness of the dielectric layers in the wafer after the metal overburden is removed. Conventionally, an off line metrology tool was needed to measure the thickness of the layers of the wafer. The embodiments of the present invention can measure the thickness of the layers of the wafer without needing to remove the wafer and measure from a separate machine. Other aspects and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

## Brief Description of the Drawings

The invention, together with further advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

Figure 1A shows a cross sectional view of a dielectric layer undergoing a fabrication process that is common in constructing damascene and dual damascene interconnect metallization lines;

Figure 1B is an illustration showing the overburden portion of the copper layer and the diffusion barrier layer having been removed by a CMP process;

Figure 2A shows a CMP system in which a pad is designed to rotate around rollers, in accordance with an embodiment of the present invention;

Figure 2B is an illustration showing an endpoint detection system, in accordance with an embodiment of the present invention;

Figure 3 is a diagram showing a portion of a wafer illuminated by a multi-spectral light during a CMP process, in accordance with an embodiment of the present invention;

Figure 4 is a flowchart showing a method for detecting an endpoint during a chemical mechanical polishing process, in accordance with an embodiment of the present invention;

Figure 5 is spectrum graph showing a broad band reflected spectrum from a wafer at various points in the CMP process, in accordance with an embodiment of the present invention;

Figure 6 is a flowchart showing a parametric linear prediction estimation method for monitoring optical resonance, in accordance with an embodiment of the present invention;

Figure 7 is a plot of roots of LP polynomial on the complex plane, in accordance with an embodiment of the present invention;

Figure 8 is the time evolution of estimated power using the proposed method due to single dielectric layer in a defined thickness range; and

Figure 9 is a graph showing the magnitudes of the peaks found during operation 414 as a function of time, which is shown as the shot number.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An invention is disclosed for optical endpoint detection using high resolution spectral analysis. The present invention provides an optical endpoint detection system that utilizes optical interference to determine when a metal layer has reached a thin metal zone during a CMP process. In particular, an endpoint is determined based on optical interference occurring in the reflected spectrum data, which is a result of phase differences in light reflected from different layers of the wafer, and occurs when the top metal layer is reduced to the thin metal zone. To provide high resolution analysis of the reflected spectrum data, embodiments of the present invention extrapolate data outside the acquired spectral range using a linear prediction technique and decompose the data into noise and signal sub-space values.

In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art that the present invention may be practiced without some or all of these specific details. In other instances, well known process steps have not been described in detail in order not to unnecessarily obscure the present invention.

Figure 2A shows a CMP system in which a pad 250 is designed to rotate around rollers 251, in accordance with an embodiment of the present invention. A platen 254 is positioned under the pad 250 to provide a surface onto which a wafer will be applied using a carrier 252. Endpoint detection is performed using an optical detector 260 in which light is applied through the platen 254, through the pad 250 and onto the surface of the wafer 200 being polished, as shown Figure 2B. In order to accomplish optical

endpoint detection, a pad slot 250a is formed into the pad 250. In some embodiments, the pad 250 may include a number of pad slots 250a strategically placed in different locations of the pad 250. Typically, the pad slots 250a are designed small enough to minimize the impact on the polishing operation. In addition to the pad slot 250a, a platen slot 254a is defined in the platen 254. The platen slot 254a is designed to allow the broad band optical beam to be passed through the platen 254, through the pad 250, and onto the desired surface of the wafer 200 during polishing.

By using the optical detector 260, it is possible to ascertain a level of removal of certain films from the wafer surface. This detection technique is designed to measure the thickness of the film by inspecting the interference patterns received by the optical detector 260. Additionally, the platen 254 is designed to strategically apply certain degrees of back pressure to the pad 250 to enable precision removal of the layers from the wafer 200.

Figure 3 is a diagram showing a portion of a wafer 300 illuminated by a broad band light source during a CMP process, in accordance with an embodiment of the present invention. The wafer 300 includes a silicon substrate 302, an oxide layer 304 disposed over the substrate 302, and a copper layer 306 formed over the oxide layer 304. The copper layer 306 represents overburdened copper formed during a Damascene CMP process. Generally, the copper layer 306 is deposited over the oxide layer 304, which is etched in an earlier step to form trenches for copper interconnects. The overburden copper is then removed by polishing to expose the oxide layer 304, thus leaving only the conductive lines within the trenches. Dual Damascene occurs in a similar manner and allows the formation of metal plugs and interconnects at the same time.

During the polishing process, embodiments of the present invention utilize optical interference to determine when the copper 306 has been removed. Initially, shown in view 301a, the copper layer 306 is relatively thick, about 10,000 Å, and thus opaque. At this point, the light 308 that illuminates the surface of the wafer 300 is reflected back with little or no interference. Then, as the copper is polished down, the copper layer 306 becomes a thin metal, at about 300-400 Å. This is known as the thin metal zone. At this point, shown in view 301b, the copper layer 306 becomes transparent and light can pass through the copper layer 306 to illuminate the layers beneath.

When the light 312 begins penetrating the various layers of the wafer optical interference occurs. Each layer of the wafer has a reflective index, which is a property that defines the layer's affect on the velocity of the light 312 as it passes from one layer to another. Hence, the velocity of the light 312 changes as the light 312 passes from one material to another.

At each layer interface the light 312 gets reflected and comes back to the optical detector. Since the velocity has changed inside the material, a phase change occurs. Thus, there is a phase difference between the light 314 reflected from the surface of the copper layer 306 and the light 316 reflected from the surface of the oxide layer 304. Similarly, there is a phase difference between the light 316 reflected from the surface of the oxide layer 304 and the light 318 reflected from the surface of the substrate 302. When the various reflected light rays 314, 316, and 318 interact an optical interference occurs.

Thus, when the copper layer 306 is thick, a phase change does not occur because the light 308 cannot penetrate the copper layer 306, and thus no interference occurs.

However, when the copper layer 306 becomes very thin and transparent, interference occurs because phase changes occur between the light reflected from the various layers of the wafer 300. At this point, the polishing process should be halted.

Figure 4 is a flowchart showing a method 400 for detecting an endpoint during a chemical mechanical polishing process, in accordance with an embodiment of the present invention. In operation 402, broad band reflectance data is obtained by illuminating a portion of the surface of the wafer with a broad band light source. Reflected spectrum data is then received corresponding to the spectrums of light reflected from the illuminated portion of the surface of the wafer. In addition, during operation 402, the reflectance data used as a normalization reference can be updated, as described in greater detail in related U.S. Patent Application No. __________ (Attorney Docket No. LAM2P253.CIP1), filed October 12, 2001, entitled "In-Situ Detection of Thin-Metal Interface Using Optical Interference via a Dynamically updated Reference," which is incorporated by reference in its entirety.

Figure 5 is spectrum graph 500 showing a broad band reflected spectrum from a wafer at various points in the CMP process, in accordance with an embodiment of the present invention. The graph 500 plots the intensity verses $1/\lambda$, where $\lambda$ is the wavelength of light in free space. Plotting intensity as a function of $\lambda$ provides a non-periodic signal when optical interference occurs. Hence, the embodiments of the present invention plot intensity as a function of $1/\lambda$, since intensity plotted as a function of $1/\lambda$ provides a periodic signal when optical interference occurs. Curve 502 shows the reflected spectrum when the copper layer of the wafer is thick, and thus opaque. As previously mentioned, when the copper layer is thick, no interference occurs because the

light cannot penetrate the copper layer and thus a phase change does not occur. This is shown by curve 502, which does not show any oscillations. As the copper layer becomes thinner oscillations begin to appear in the reflected spectrum, such as shown in curves 504a and 504b, each representing the reflected spectrum at various points in time when the copper is transparent.

More specifically, graph 500 shows that periodic fringes or oscillations begin appearing in the reflected spectrum in the $1/\lambda$ or 1/nm axis, where nm is $10^{-9}$ Meters, when the copper layer thickness approaches the penetration depth. Each curve in Figure 5 is an instance of the reflectance spectrum $R(1/\lambda)$ where $\lambda$ is from 300 to 700nm. The approximate relation for the ratio of the magnitude of electric field of the reflected wave to the incident wave for a single layer of dielectric on a substrate is given by equation (1) below:

(1) $R(1/\lambda) = r_{01} + r_{12}\, e^{-i2\pi\beta}$

Where, $r_{01}$ and $r_{12}$ are the Fresnel's coefficients. $\beta$ is the phase angle given by equation (2) below:

(2) $\beta = 2n_1 d/\lambda$

where d is the thickness of the dielectric layer and $n_1$ is the reflective index of the dielectric.

Referring back to Figure 4, the reflectance data is normalized in operation 404. Normalizing the reflectance data reduces the sample to sample variations in the data. As mentioned previously, when the endpoint window in the polishing belt moves over the

endpoint detection sensor, the surface of the wafer is illuminated by broad band light and the light reflected from the wafer surface is recorded as reflectance data. Since small variances in the data can occur because of outside factors, the reflectance data is normalized to reduce the effect the variances have on the endpoint detection process.

In operation 406, the normalized reflectance data is de-trended using a polynomial fit. De-trending stretches out the reflectance curve to reduce oscillations present when the copper layer is still opaque, which can be caused by factors other than optical interference from the underlying wafer layers. To this end, a polynomial is fitted to the reflectance data and then later subtracted out. In this manner, the reflectance data curve begins essentially flat, thus allowing for easier detection of oscillations caused by the optical interference of the various layers of the wafer.

In operation 408, a moving average filter is applied along the $1/\lambda$ axis. Typically, an amount of high frequency noise is present in the reflectance data curve. The high frequency noise can adversely affect the endpoint detection process. Thus, a filter is applied to the curve to reduce the high frequency noise.

A derivative transform is then applied to the reflectance data in operation 410. Generally, a constant bias, or DC, is present in the reflectance data collected from the wafer surface. Since the constant bias in the reflected spectrum can be large, a large peak at the origin can dominate an equation for power in a defined spectral range. This can dominate and obscure the peaks at the higher regions of the spectrum, which are of primary interest. By applying the derivative transformation to the reflectance data, the constant bias can be reduced or eliminated. In graphical terms, the reflectance data curves can be zero centered by removing the constant bias.

In operation 412, a linear prediction estimator is applied to the reflectance data. The linear prediction estimator breaks down the signal into multiple components. Hence, the linear prediction estimator can be used to better detect the occurrence of an oscillating pattern in the reflected spectrum.

As mentioned above, embodiments of the present invention determine the endpoint of a CMP process based on the onset of optical resonance occurring when the metal thickness approaches the penetration depth of the visible range of the electromagnetic spectrum. To detect the optical resonance, embodiments of the present invention monitor the power in a defined spectral range of the reflected spectrum within a region of layer thickness. A Fourier Transform (FT) can be used to determine and monitor the PSD, as described in greater detail in U.S. Patent Application No. 09/812,535, filed March 19, 2001, entitled "In-Situ Detection of Thin-Metal Interface Using Optical Interference," which is incorporated by reference.

However, in some instances greater resolution may be required because the length of the data samples collected limits the FT resolving power, which is defined as the shortest distance between two spectral peaks that can be resolved unambiguously. For example, the FT resolution for a spectrometer that acquires spectral data in the range of 300nm to 700nm is given by (700*300)/ (700-300) = 525nm or 5250 Å. As a result, peaks that are located about 5000 Å apart are difficult to distinguish. Further, an FT requires a smoothing window function to handle truncation artifacts, which broadens the peaks and compromises the resolution.

To address these issues, embodiments of the present invention utilize a parametric method that does not assume the data segment is periodic or zero-padded outside the

acquisition range as is done by the FT method. Figure 6 is a flowchart showing a parametric linear prediction estimation method 412 for monitoring optical resonance, in accordance with an embodiment of the present invention. In operation 602, a data matrix is formed. The reflectance data obtained from the wafer surface is organized into a data matrix, such as data matrix 602a shown in Figure 6. The data matrix 602a includes rows of spectrum pixel values, each row comprising M pixel values. Preferably, M is number that is greater than the number K of frequencies/thicknesses that will be present when the thin metal zone is reached, frequency corresponds to a layer between opaque metal layers in the wafer. M should be greater than the number of layers in the wafer between opaque metal layers.

In operation 604, the reflectance data is decomposed into noise and signal subspace. A singular value decomposition (SVD) is used to reject the noise in the reflectance data by keeping the largest singular values and zeroing the other values, as illustrated in operation 604 of Figure 6. Hence, the data is projected onto the signal sub-space using the SVD.

In operation 606, linear prediction coefficients are determined. Data is extrapolated outside the acquired spectral range using a linear prediction technique, which generates values outside the acquired spectral range using a linear combination of values collected within the acquired spectral range. By extrapolating data outside the acquired spectral range, resolution can be enhanced. The prediction coefficients can be determined by solving a set of linear equations that predict values outside the measured domain as dependent variables, which are linear combinations of values in the available region of spectrum as independent variables. The amplitude and phase of each harmonic

component is related to the linear prediction coefficients and can be determined by finding the roots of a characteristic polynomial obtained from the linear prediction coefficients. The stable complex roots of the polynomial give the amplitude and phase of the damped sinusoidal components. Stability can be checked by investigating the location of roots on the complex plane with respect to a unit circle. Figure 7 is a plot 700 of roots of LP polynomial on the complex plane, in accordance with an embodiment of the present invention. The plot 700 illustrates the roots plotted on the complex plane. As can be seen, the plot 700 shows four roots 702 are outside the unit circle 706 and one root 704 is inside the unit circle 706.

In other embodiments, where the wafer structures are more complicated, the frequencies determined by the linear prediction/SVD step represent the geometrical layout of the layered structure. For example, in a two layer structure with thickness $d_1$ and $d_2$, the primary frequencies will appear at $d_1$ and $d_1 + d_2$. Embodiments of the present invention use this property to detect and flag the first instance during the CMP process when a metal layer reaches the thin metal zone or penetration depth. For copper the penetration depth is about 500 Å and for Tungsten it is about 800 Å.

Referring back to Figure 4, a specific number of frequencies are found in the linear prediction step within predetermined thickness bounds, in operation 414. When the thickness of the underlying dielectric layer is known, reasonable bounds can be determined. Figure 8 is the time evolution of estimated power using the proposed method due to single dielectric layer in a defined thickness range. In the example of Figure 8, the thickness of the dielectric layer below the copper layer is in the range of 6000-10000 Å. Thus, the bounds 800 are configured to monitor the power in a defined spectral range of

the reflectance spectrum within the bounds established by a low thickness bound (LTB) and a high thickness bound (HTB). Thus, referring back to Figure 4, during operation 414 a predetermined number of harmonic components are found between the thickness bounds defined by LTB and HTB.

Next, in operation 416, the squared value of amplitudes found in operation 414 are summed to obtain the power in the defined spectral range. Figure 9 is a graph 900 showing the power in a defined spectral range found during operation 414 as a function of time, which is shown as the shot number. The shot number represents the sequence of the reflectance data obtained during consecutive iterations of the endpoint detection process. As shown from graph 900, the power in the defined spectral range 902 remains low during the earlier stages of the CMP process, in this example, during shots 1 to about 84. Then, as the copper approaches the thin metal zone at about shot 90, the power in the defined spectral range 902 rises sharply because of the oscillations occurring in the reflected spectrum data as a result of optical interference when the copper layer becomes thin and transparent.

Referring back to Figure 4, a decision is made as to whether the estimated power in the defined spectral range value is greater than a predefined threshold, in operation 418. The threshold is generally selected so as to estimate when the thin metal zone has been reached. Typically the threshold is selected so as to be high relative to the sum of the peak magnitudes when the thickness of metal layer is large compared to the penetration depth. If the power in the defined spectral range found in operation 414 is less than the predefined threshold, the method 400 continues to obtain the next broad

band reflectance data in operation 402. Otherwise, the method 400 is completed in operation 420.

The CMP process is terminated in operation 420, since at this point the endpoint has been reached. In other embodiments of the present invention, statistical hypothesis tests can be conducted on the power in the defined spectral range signal to determine when the thin metal zone has been reached. Since the embodiments of the present invention use optical interference instead of mere changes in the surface reflectivity as in conventional endpoint detection, the embodiments of the present invention advantageously provide increased sensitivity and robustness in endpoint detection. In addition to endpoint detection, the embodiments of the present invention advantageously can be used to determine the thickness of the layers in the wafer. Conventionally, an off line metrology tool was needed to measure the thickness of the layers of the wafer. The embodiments of the present invention can measure the thickness of the layers of the wafer without needing to remove the wafer and measure from a separate machine.

Although the foregoing invention has been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications may be practiced within the scope of the appended claims. Accordingly, the present embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalents of the appended claims.

***What is claimed is:***